



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>5</sup> : <b>H04R 25/00</b></p>	<p><b>A1</b></p>	<p>(11) International Publication Number: <b>WO 95/08907</b> (43) International Publication Date: 30 March 1995 (30.03.95)</p>
<p>(21) International Application Number: PCT/US94/10009 (22) International Filing Date: 2 September 1994 (02.09.94) (30) Priority Data: 08/123,961 20 September 1993 (20.09.93) US (71) Applicant: NOISE CANCELLATION TECHNOLOGIES, INC. [US/US]; 1015 West Nursery Road, Linthicum, MD 21090 (US). (72) Inventor: HOGE, William, J., J.; 691 Johahn Drive, Westminster, MD 21157 (US). (74) Agent: HINEY, James, W.; Noise Cancellation Technologies, Inc., 1015 West Nursery Road, Linthicum, MD 21090 (US).</p>		<p>(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published <i>With international search report.</i></p>
<p>(54) Title: OPTIMUM HEADSET AND METHOD OF ADJUSTING SAME (57) Abstract  An optimum anti-noise headset (10) designed to optimize the phase and magnitude responses involved in canceling noise in a series of chambers separated by a diaphragm (20) and a depressed member (16) with an aperture (18) therein, respectively.</p> <div data-bbox="941 1218 1380 1743"> </div>		

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## OPTIMUM HEADSET AND METHOD OF ADJUSTING SAME

This invention relates to a method of and apparatus for improving the performance of headsets and has particular applications in active noise control and high fidelity audio systems.

One of the simplest forms of a headset is an electrodynamic driver mounted directly over the listener's ear. This is the basis of Bell's first telephone patent. Most theoretical development for headsets has proceeded from the requirements of the telephony. The bandwidth of each channel in a telephone system is typically limited, so the frequency response required of a telephone headset is not as wide as might be desired in a high fidelity audio system. Although an electrodynamic driver is assumed for the purpose of illustration, the principals apply to other forms of transduction as well.

### Prior Art

Commercial headsets for wide bandwidth applications have typically been designed using the forms developed for earlier applications with the application of band-aids to extend the unit's response. This improvement can result in a physical arrangement of components which has a topology similar to that of prior designs; however, the mechanical dimensions and electromechanical properties of the headset will be optimized with respect to the desired response.

Prior efforts at designing loudspeakers and headsets have been described in Olson, H.F., *Acoustical Engineering*, Van Nostrand, New York, 1957, Small, R. H., *Electrodynamic Direct-Radiator Loudspeakers*, Ph.D. Thesis, University of Sydney, 1971, and Thiele, A. N., "Loudspeakers in Vented Boxes (Parts I and II)", reprinted in *Loudspeakers*, Audio Engineering Society, New York, 1978. None of the references suggest a way to design a headset to optimize both the phase response and the magnitude response of the system. In active noise control, optimization of these responses is critical in obtaining optimal performance parameters.

To accomplish this goal it is necessary to develop a transfer function that will allow one to shape the system electrically as well as mechanically.

Accordingly, it is an object of this invention to provide a headset design wherein the configuration is shaped both electrically and acoustically to maximize phase and magnitude response.

Another object of this invention is to provide a method of configuring the electrical and mechanical shape of a headset to maximize phase and magnitude response.

A still further object of this invention is to provide a transfer function for optimizing the design configurations for headsets.

These and other objects will become apparent when reference is had to the accompanying drawings in which

Figure 1 is a cross-sectional view of one earpiece on a headset designed according to this invention.

5 Referring now to Figure 1 there is shown the earpiece generally designated as 10. Earpiece 10 is generally circular in plan view and is designed to abut the head 11 of a user to surround ear 12. Sealing means such as a beading 13 can be employed around the periphery of the earpiece 10 to seal the inner space. Housing 14 of earpiece 10 extends outwardly and is sealed. A partition wall 15 extends inwardly from 14 and has  
10 an annular depression 16 depending therefrom. A circular base 19 with an aperture 18 therein defines, together with a diaphragm 20, a front cavity or chamber. The diaphragm with the inner wall of housing 14 defines the equivalent of a closed box loudspeaker means or outer chamber. The space between the ear and front chamber is defined as the ear cavity or ear chamber.

15 To design the exact configuration for the active noise cancellation function that is called for, such as that in Figure 1, a transfer function dictates the design.

Consider an electrodynamic headset as in Figure 1. For frequencies low enough for a lumped-parameter model to be valid, the transfer function  $T(s)$  of the headset is

$$20 \quad T(s) = \frac{p_Z(s)}{E_g(s)} = \frac{\rho_0 c^2 B I S_D}{M_{MSR} E V_Z} \frac{\omega_F^2}{s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4}$$

The list of symbols used in this transfer function are as follows

- 25  $\mu$  front cavity compliance ratio ( $C_{MT}/C_{MF}$ )
- $\rho_0$  density of air (1.18 kg/m<sup>3</sup>)
- $\omega_C$  resonance frequency of the equivalent closed-box loudspeaker (rad/s)
- 30  $\omega_F$  resonance frequency of the front cavity compliance and outlet mass (rad/s)
- $\omega_Z$  resonance frequency of the ear cavity compliance and the front cavity outlet mass (rad/s)
- 35  $c$  speed of sound (345 m/s)
- $BI$  electromagnetic coupling coefficient (N/A)
- $C_{MF}$  equivalent mechanical compliance of the front cavity (m/N)
- 40  $C_{MT}$  mechanical compliance of the equivalent closed-box loudspeaker (m/N)

- $E_g$  source output potential (V)
- $M_{MS}$  effective diaphragm moving mass (kg)
- 5  $p_Z$  sound pressure in the ear cavity (Pa)
- $Q_F$  quality factor of the front cavity resonator
- $Q_{TC}$  total quality factor of the equivalent closed-box loudspeaker
- 10  $R_E$  voice coil resistance ( $\Omega$ )
- $S_D$  effective diaphragm area ( $m^2$ )
- 15  $V_Z$  volume of the ear cavity ( $m^3$ )

The coefficients of the polynomial are

$$\begin{aligned}
 a_1 &= \omega_C / Q_{TC} + \omega_F / Q_F, \\
 a_2 &= (\mu + 1) \omega_C^2 + \omega_F^2 + \omega_Z^2 + \omega_C \omega_F / (Q_{TC} Q_F), \\
 a_3 &= \omega_C^2 \omega_F / Q_F + (\omega_F^2 + \omega_Z^2) \omega_C / Q_{TC}, \text{ and} \\
 a_4 &= (\mu + 1) \omega_C^2 \omega_Z^2 + \omega_C^2 \omega_F^2.
 \end{aligned}$$

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Note that this function has no zeroes. If leaks around the ear are ignored, then the unit may be considered to be direct coupled. That is, dc applied to the voice coil will result in a static pressure in the ear cavity. We can consider that the response of the earphone is a 4-pole low-pass filter.

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Given this transfer function, it is possible to synthesize a system with a desired 4th-order response including, but not limited to, Butterworth (B4), Chebychev (C4), Subchebychev (SC4), Bessel (BL4), or Boom-Box (BB4); or it may be quasi-3rd-order, such as Quasi-Butterworth (QB3). The polynomials for each of these forms are documented in the literature. Practical limits will apply on the physical realizability of a system. For instance, the principal source of damping in the system is typically from the back emf of the motor. Since increased bandwidth requires increased damping, the size of the motor assembly necessary to realize a very wide bandwidth system may be impractical. However, if reduced efficiency can be tolerated, acoustical damping may be introduced with the system synthesis specifying the location and amount of damping.

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The basic synthesis method follows that used in modern electrical filter theory. First, class of response shape is selected. Second, it is frequency-scaled, that is, the

response shape is placed at the desired portion of the frequency domain. Third, a parameter of one of the system components or a load impedance is selected to impedance-scale the system. Typically, the dimensions of the ear cavity specify the load. Fourth, the other system parameters are synthesized.

## CLAIMS

1. An improved active noise headset having one or more earpieces, said headset comprising
  - 5 an ear chamber means adapted to be placed adjacent a user's ear,
  - a front chamber means adjacent said ear chamber means and in acoustical connection therewith,
  - an outer chamber means adjacent said front chamber and separated therefrom by a diaphragm means,
  - 10 wherein said chamber configurations are such as to maximize phase and magnitude response.
2. A headset as in claim 1 wherein said acoustical connection between said ear chamber and front chamber is an aperture means.
- 15 3. A headset as in claim 1 wherein said chamber configurations and their interrelationship have been designed according to the transfer function
 
$$T(s) = \frac{p_Z(s)}{E_g(s)} = \frac{\rho_0 c^2 B / S_D}{M_{MSR} E V_Z} \frac{\omega_F^2}{s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4}$$
- 20 4. The method of designing an active noise cancellation headset comprising
  - providing an ear cavity, front cavity and outer speaker cavity,
  - providing an aperture between said ear cavity and front cavity and
  - configuring said cavities so as to maximize phase and magnitude of said
  - 25 headset.
5. The method of claim 4 wherein said configuring of the cavities is done according to the transfer function

$$30 \quad T(s) = \frac{p_Z(s)}{E_g(s)} = \frac{\rho_0 c^2 B / S_D}{M_{MSR} E V_Z} \frac{\omega_F^2}{s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4}$$

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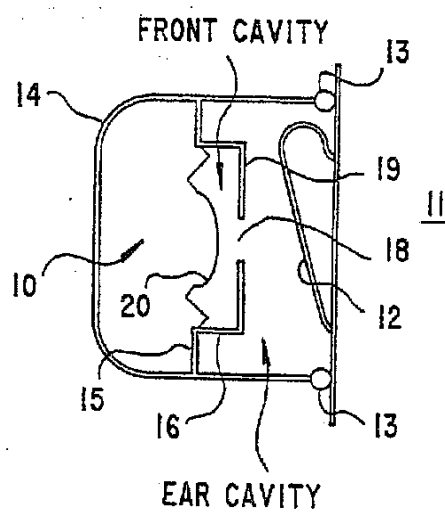


Fig. 1

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/10009

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H04R 25/00

US CL :381/183,187 and 72.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 381/183,187, 72,71,74 AND 25;  
379/430.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	US, A, 4,922,542 (SAPIEJEWSKI) 01 May 1990. See figures 2 and 3.	1,2 and 4. --- 3 and 5
A	US, A, 4,644,581 (SAPIEJEWSKI) 17 February 1987. See figure 3.	1-5.
A	US, A, 5,181,252 (SAPIEJEWSKI) 19 January 1993. See figure 2.	1-5



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search

07 DECEMBER 1994

Date of mailing of the international search report

13 JAN 1995

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